DEVELOPMENT OF COATING FOR FORMALDEHYDE SCAVENGERS IN WOOD COMPOSITE

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ABSTRACT

Wood composite is also known as wood engineering. This field is available due to its ability to overcome the current limitation faced by applying natural lumber wood. The many advantage that wood-composite have over natural lumber makes it more desirable in long-term usage. In the production of wood-composite, the agent use to bind wood together is urea formaldehyde. The issue faced when urea formaldehyde is used, that it will produce free formaldehyde which is rather cancerous to human beings. Hence, steps have to be taken to reduce the emission of urea formaldehyde. The step proposed in this research is utilizing formaldehyde scavengers. But if scavengers are applied directly during the production of wood composite, it will affect the credibility of the product and also react will the urea formaldehyde. Thus, a study on developing a typical wax or polymer coating for these scavengers could solve the problem. Once, the coating is developed, it is incorporated to the preparation of the medium density fibreboard and after that, tests are conducted to characterize its properties. To study the feasibility of success of this research, the parameter studied is mechanical properties of the wood and the formaldehyde emission of the finished product. The focus of mechanical properties is the internal bonding, modulus of elasticity and modulus of rupture to determine effect of scavengers to the wood panel. In formaldehyde emission, perforator and desiccator methods are applied to determine the concentration of formaldehyde liberated. From the proposed scavengers used, sodium metabisulfite and ammonium bisulfite, sodium metabisulfite shows great effectivity in reducing the formaldehyde liberation followed by ammonium bisulfite. However, ammonium bisulfite affected the mechanical properties of the board greatly, where else, sodium metabisulfite did not affect adversely. With this study, it could provide the wood-composite industry an alternative to open new market with this method of producing wood-composite products.

ABSTRAK

Kayu komposit dalam erti kata lain adalah kejuruteraan kayu. Bidang ini wujud kerana keupayaannya untuk mengatasi kekurangan-kekurangan yang dihadapi oleh kayu semula jadi. Kelebihan-kelebihan menggunakan kayu komposit membuatkannya diingini dalam jangka panjang. Dalam pembuatan kayu komposit, agen pengikat yang digunakan adalah urea formaldehid. Masalah yang dihadapi apabile urea formaldehid digunakan adalah pelepasan formaldehid yang juga boleh menyebabkan pertumbuhan barah dalam kalangan manusia. Oleh sebab itu, langkah pencegahan harus diambil untuk menggurangkan pelepasan formaldehid. Langkah yang dicadangkan adalah penggunaan pemungut formaldehid dalam proses pembuatan kayu komposit. Tetapi, jikalau pemungut ini digunakan di masa pembuatan kayu komposit, pemungut ini boleh merosakkan kualiti produk atau bertindak balas dengan urea formaldehid. Jadi, suatu salutan atas pemungut dikaji dan dibangunkan. Selepas salutan ini dicipta, pemungut ini akan digabungkan dalam proses pembuatan kayu komposit. Untuk menyimpulkan penyelidikan ini, ciri-ciri mekanikal akan dikaji dan pelepasan formaldehid ditentukan. Dalam kajian ciri-ciri mekanikal, ikatan dalaman, modulus keanjalan dan modulus pecah akan ditentukan dalam papan serat kepadatan sederhana (MDF). Dalam kajian pelepasan formaldehid pula, beberapa kaedah akan diambil dalam menentukan kadar pelepasan formaldehid. Antaranya, kaedah “perforator” dan kaedah “desiccator”. Dengan pemungut yang dicadangakan adalah natrium metabisulfite dan ammonium bisulfite, pelepasana formaldehid adalah lebih rendah apabila natrium metabisulfite digunakan daripada ammonium bisulfite. Walau bagaimanapun, ammonium bisulfite telah menjejaskan ciri-ciri mekanikal terlalu rendah tetapi natrium metabisulfite hanya menjejaskan sikit ciri-ciri mekanikal kayu komposit. Dengan kajian ini, adalah dengan harapan boleh memberi industri kayu komposit suatu alternatif dalam perwujudan pasar baru dengan kaedah baru pembuatan produk kayu komposit.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASTM	American Standard of Testing & Materials
CARB	California Air Resources Board
EN	European Nation (standard)
F/U	Formaldehyde to Urea
FRIM	Forest Research Institute of Malaysia
IARC	International Agency for Research on Cancer
IB	Internal Bonding
JAS	Japanese Agricultural Standard
JIS	Japanese Industrial Standard
MDF	Medium Density Fibreboard
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
NPA	Notice of Proposed Amendment
RH	Relative humidity
UF	Urea Formaldehyde
UTM	Universal Testing Machine
WPC	Wood Plastic Composite

1 INTRODUCTION

1.1 Motivation and statement of problem

With strict laws and policies like Malaysia's very own National Forestry Act 1984, to protect natural wood from illegal logging and harvesting, it has been difficult for avid natural wood-lover to purchase or satisfy their passion. Hence, wood-composite makes a suitable and the most promising alternative to solve this issue.

Wood-composite is viable in the form of medium-density fibreboard (MDF), particleboard, oriented strand board, plywood, etc. The manufacture of composite wood-based products occurs when various sources of wood particles are bind with a thermosetting binding agent which is usually a type of resin. This will eventually form into compacted mats which are rather loose. These wood-particles are also varied in many different forms. Such examples are like flakes, fibres, strands, and particulate forms. Different wood-particles yield different type of boards. The generic end products are fibreboard, hardboard, flakeboard, strandboard, particleboard, and waterboard to name a few. Unlike hardboard and medium-density fibreboard, these boards are characterised in terms of their density. Back to production or preparation of wood composite, the mats are then placed in mould and pressed until it reaches a suitable or preferred thickness using a hot-press machine. Then, it is left to cool down until the adhesive or resin is cured. (Taylor & Reid, 1984).

The resin which is usually utilised is urea formaldehyde resin. Approximately, urea formaldehyde resin is responsible for at least 90% or more in the world's wood-composite board production (Maloney, 1993). Moreover, urea formaldehyde is the most popular amino resins (William, 1991). From the amino resins manufacturing in the industry, urea formaldehyde comprises of 80% of the amino resins produced worldwide and the rest belongs to the rest of the amino resin group, primarily melamine-formaldehyde (Conner, 1996). The properties which make urea formaldehyde very much desired in the wood-composite industry as the main adhesive are as follow:

- Cheap and low in production cost,
- Solubility towards water,
- Low curing temperature,
- Resistive to abrasion and microorganisms,
- Fast reaction time under hot press,
- Excellent thermal stability,
- Lack of colour, and
- Its adaptability properties to wide array of curing conditions (Maloney, 1993, Dunky, 1998 & Conner, 1996).

Unfortunately, the ultimate drawback for utilising urea formaldehyde in wood-composite is the emission of free formaldehyde to the surrounding. Formaldehyde is labelled as a carcinogenic toward humans, which makes it very much cancerous. The International Agency for Research on Cancer (IARC, Monograpgh on the evaluation of carcinogenic risk to human, 2006) classified formaldehyde as "carcinogenic to human (Group 1). On top of that, a policy imposed by the California Air Resources Board (CARB) imposes restriction which limits formaldehyde emission. This resulted in greatly on the wood-based panel industry (Costa, et al., Scavengers for achieving zero formaldehyde emission of wood-based panels, 2013).

Hence, to overcome this major issue, many research have been done to reduce or eliminate if all, the emission of urea formaldehyde. Some methods which are currently being research and practiced in the industry are reduction of formaldehyde to urea (F/U) ratio, substitution of urea formaldehyde resin, and usage of urea formaldehyde scavengers (Costa, et al., 2013).

1.1.1 Reduction in formaldehyde to urea (F/U) ratio

Myers has studied on the F/U ratio and concluded the contradicting standards set by respective responsible agencies in different countries do not match up (Myers, 1984).

- F/U < 1.2 or < 1.1 to meet German standard
- F/U < 1.3 or < 1.22 to meet NPA emission standards for U.S. mobile homes
- F/U ≥ 1.2 for bending strength and modulus of rupture

- F/U ≥ 1.1 or possibly ≥ 1.2 for internal bond
- F/U ≥ 1.2 or ≥ 1.3 for 24-hours thickness swell.

Eventually, based on Myers extensive study, he found out that the bending strength and modulus of rupture was thoroughly affected when the F/U dropped to 1.2. Internal bond however, are at an acceptable manner but started deteriorating when the F/U ratio increase to 1.4 or 1.5. Besides that, the thickness swell begins rapidly as F/U falls to 1.3 onwards. Most importantly, the reactivity of urea formaldehyde decreases as the F/U ratio reduces.

1.1.2 Substitution of Urea Formaldehyde

Substitution of urea formaldehyde adhesive with a formaldehyde-free compound could be very promising. Unfortunately, due its higher price and lower reactivity, industrial producers are not convinced (Amazio, et al., 2011). A research done (Despres, et al., 2010) suggested that substituting dangerous urea formaldehyde with alternative, non-toxic, non-volatile aldehydes to produce urea-based resins. Unfortunately, these aldehydes have a significant problem, it is coloured (Pizzi, 1983). Besides that, they are also toxic to some level and are have reactivity issues with other compounds present in the binding agent (Mansouri & Pizzi, 2006) (Wang & Pizzi, 1997).

1.1.3 Usage of urea formaldehyde scavengers

Usages of urea formaldehyde scavengers are relatively new in the industry. Scavengers are compound utilized to extract or remove a certain substance by either reacting with it or being adsorbing it. Many researches have been done to signify the gain in benefits by using scavengers to reduce urea formaldehyde emission. The usage of natural or biological-based urea formaldehyde scavengers is very common in the industry to reduce urea formaldehyde emission (Kim, et al., 2006). Studies have shown that scavengers like sodium metabisulfite ($Na_2S_2O_5$) is very efficient in particleboards produced with urea formaldehyde and melamine-formaldehyde (MF) resin and yielded successful results (Costa, et al., 2012).

1.2 Objectives

The following are the objectives of this research:

- To develop a coating for urea formaldehyde scavengers either with a suitable wax or a type of polymer.
- To analyse the mechanical properties of the medium-density fibreboard which are; internal bonding, modulus of rupture, and modulus of elasticity.
- To investigate the free formaldehyde emission rate of the wood composite board fabricated.

1.3 Scope of this research

The following are the scope of this research:

i) Perform a study on the affectability of wax and polymer for a coating used in the preparation of scavengers. This coating is via trial and error method.

ii) Emission of formaldehyde is to be studied after the completion of the fibreboard.

iii) The mechanical properties like internal bonding, modulus of rupture, and modulus of elasticity of the board are to be studied via utilizing the universal testing machine (UTM)

1.4 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a detailed description of this research literature review. It comprises of three main parts, which is wood composite, urea formaldehyde, and scavengers. A general description about the economic point of view is also discussed. Lastly, a summary of predicted parameters are identified to give an overview on the variation by manipulating each parameters.

Chapter 3 gives an overview on the characterization efforts in the process of investigating the efficiency of scavengers in formaldehyde emission, the mechanical properties of the board and the coating of scavengers. Moreover, this chapter will portray the experimental methodology of this research.

Chapter 4 is devoted to a comparative study on the predicted experimental results with the future expected results. Further discussion and justification regarding possible deviation of data are hypothesized.

2 LITERATURE REVIEW

2.1 Overview

This paper presents the experimental studies mainly on the development of coating for scavengers, the effectivity of scavengers toward formaldehyde and also the mechanical properties of the board utilizing coated scavengers. This chapter will subdivided into three different parts which each plays an important role. The subchapters which will be included in this chapter are as follow:

- Wood composite,
- Urea formaldehyde, and
- Scavengers.

A detailed insight will be presented regarding each subchapter. Lastly, a summary of predicted parameters are identified and explained further.

2.2 Wood composite

Wood composite is also known as wood engineering. This field is developed to overcome the limitations faced by general wood. Some of the advantages of using wood composite over actual wood lumber are as follow:

- It is less likely to split,
- It is lighter for easier handling,
- It is scratch and stain resistant,
- Low cost,
- Low CO_2 emission,
- Biodegradable and renewable, and
- Mould resistant this makes its interaction with microorganism relatively impossible (Ashori, 2008).

With that in mind, this gives wood composite a longer lifespan than actual wood lumber. This concludes that wood composite overcomes the disadvantages faced by actual wood lumber in every possible manner. As the name goes, it is a composite material which is a mixture of wood or plant fibres and binding agent (Ashori, 2008). Moreover, waster wood materials can be utilised in the production of wood composite. This will be very beneficial to the environment and cost-saving which could maximize the use of raw materials and reduction of waste creation (Trost, 2002). What makes wood composite unique and different with each other is the composition of binding agent. Some wood composite can are added with wax to promote its water resistive properties and some are added with certain dense compound to make it stronger, heavier or tougher.

In economic perspective, wood composite or wood-plastic composite has a large market in the industry worldwide. Globally, there are four main factors that make use of naturals fibres and wood in plastic attractive:

- Enhanced specific properties,
- Reduction of price of materials,
- Improve the bio-based share, and
- More easily recyclable when compared to other composites.

The wood-composite production reached 1.5 million extruded tonnes after more than 30 years in the marker. This makes about 750,000 tonnes of wood which only a small fragment of the total timber market. (Eder & Carus, 2013). This shows that wood-composite is does not harm the environments as much as the other activities since only a small amount of wood is being utilized in this industry. Wood composite is a growing market (Haider & Eder, 2010) as in Europe and with that arguably throughout the whole world.

Application of wood plastic composite (WPC) varies from furniture to consumer goods. Even it can be broken down into three different components and each components are exampled as follow:

- Outdoor applications
    - Noise barrier in street construction and sheet piling for landscaping
    - Garden furniture and fences
    - Construction and safety sector, especially in decking, railings, window frame, porches and docks
    - Piping, core pipes

- Indoor applications
    - Automotive engineering (interior)
    - Trucks and containers
    - Doors, furniture parts, kitchen cupboard frames, furniture
- Consumer goods and niche products
    - Musical instruments
    - Toys
    - Household electronics
    - Frames (Eder & Carus, 2013).

2.3 Urea Formaldehyde

Urea formaldehyde is the most well-known amino resin in the wood composite industry (Boran, et al, 2011 & Dunky, 1998). As stated before, urea formaldehyde is used as a binding agent in the wood composite industry because of it unlimited array of benefits. To recap, urea formaldehyde is chosen to be the prominent thermosetting plastic resin r binding agent in wood composite for its financial benefits, able to adapt to many curing conditions, faster reaction time, solubility towards water, low curing temperature, resistive properties towards microorganisms, and its colourless qualities (Pizzi, 1983 & Conner, 1996).

2.3.1 Chemistry of urea-formaldehyde resin formation

Generally, urea formaldehyde is formed in a two stage reaction. In general, these reaction main reactants are urea and formaldehyde. Initially, urea is hydroxymethylotated by the addition of formaldehyde into the amino resin group.

Mono-, di-, and trimethylolurcas are yielded from this reaction, as shown in Figure 2.3.3.1-1. This reaction rate is very dependent on the pH range (de Jong & de Jonge, 1953). For the exact ratio of formaldehyde to urea, F/U is affected by the operation conditions in the addition reaction.

The second stage for urea formaldehyde preparation is condensation. Likewise, the rate of condensation reaction is also very dependent on the pH range of the operation. Practically, condensation occurs only during acidic pHs. The range of pH values and rate of reaction is shown in Figure 2.3.3.1-2.

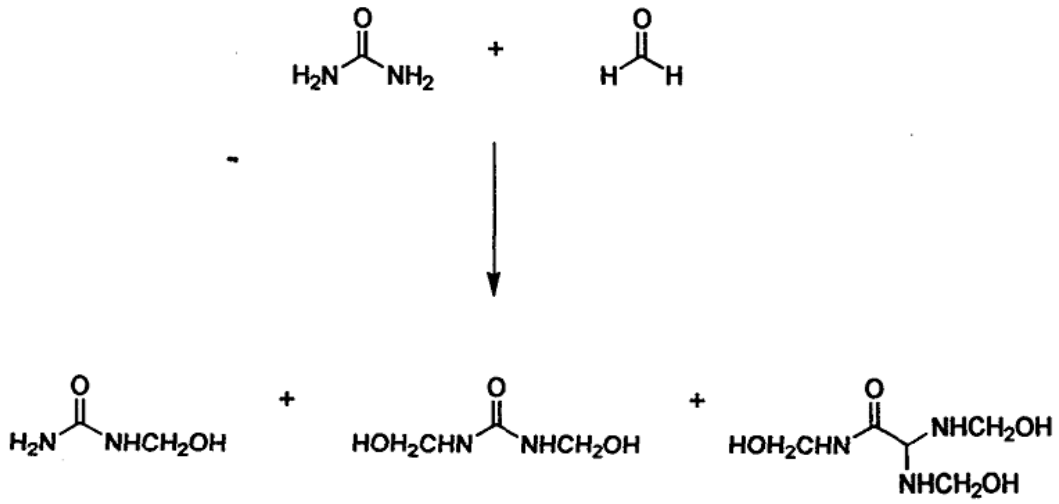

Figure 2.3.3.1-1: Formation of mono-, di-, and trimethylolurcas by addition of formaldehyde to urea (Conner, 1996).

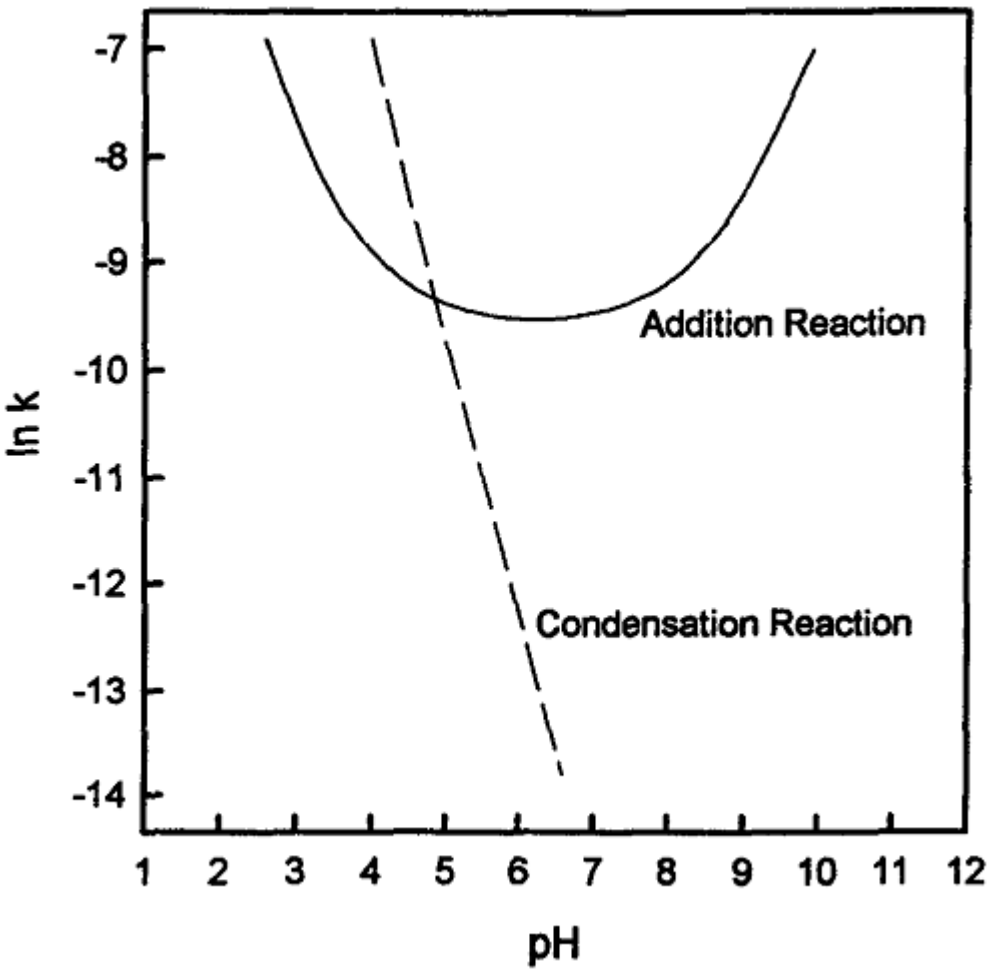

Figure 2.3.3.1-2: Influence of pH on the rate constant (k) for addition and condensation reaction in urea formaldehyde production (de Jong & de Jonge, 1953).

Similarly, in the case for urea formaldehyde resin production, it involves two major steps, addition of formaldehyde to urea and condensation method. The first step is formation of methylolurcas under basic condition of around 8.9 in the pH value. In this step also, the range of formaldehyde to urea, F/U ratio is determined and defined. Secondly, condensation process occurs under acidic condition of about 5 in the pH value. Once, the reaction is completed, the mixture is cooled and neutralized. Water, a by-product is then removed via vacuum distillation until desired viscosity. If it solidifies, formaldehyde makes excellent thermal insulator and it is also light weight (Meyer L. S., 1951). In the second step however, the F/U ratio can also be altered. In the second step, usually urea is added to lower the final F/U ratio (Conner, 1996).

The resin outcome from this process usually cures around the temperature of 120 ^{o}C in a very acidic condition (pH < 5). For curing time however, it is assumed to be similar to acid condensation of methylolurcas. The formation of a cross-linked polymeric network for the hardened, cured resin gave rise to this traditional viewpoint. Research has also shown that curing also occurs in colloidal phase (Pratt, et al., 1985).

2.3.2 Formaldehyde emission for UF resins

All good things do have certain drawbacks and for the case of urea formaldehyde, it has one major issue which affects living things adversely. Using urea formaldehyde seems to be the most suitable binding agent in the wood composite industry, but unfortunately urea formaldehyde release free formaldehyde to the surrounding. Roffael studied on this matter and found out that it is affected by exogenous factors like air humidity, air exchange and temperature. Besides that also, it is also affected by endogenous factors like raw material species, type of resins used and production conditions (Roffael E. , 1993) This emission is an important factor in the evaluation of the environment and health effects of this industry (Risholm-Sundman, et al., 2007). Moreover, formaldehyde-based wood composite products emits these free formaldehyde has cause many customers to portray discomfort and dissatisfaction towards the industry. Cause of health problems among customers can be traced back to these products, outcome from this industry (Boran, et al., 2011). Research has shown that the common health problems faced by customers who come in contact with the emitted free formaldehyde are irritation in the eyes and resporitory issues (Kim & Kim, 2004).

Also, as stated before, exposure to low concentration of formaldehyde causes minor health problems like irritation in the eyes and respiratory issue, but prolonged exposure could lead to risk of serios poisoning, chronic toxicity and eventually cancer (IARC, 2006 & Tang, et al., 2009). With health risks imposed on living being, regulations and steps have to be taken to overcome these serious issues. Also, standards and policies set by agencies worldwide affected the wood composite industry to reduce or eliminate if all the formaldehyde emission from wood products on a world-wide scale. In response to the standards and policies, companies pioneering in wood composite has taken major stride to reducing the formaldehyde emission level as shown in Figure 2.3.3.1-1 .

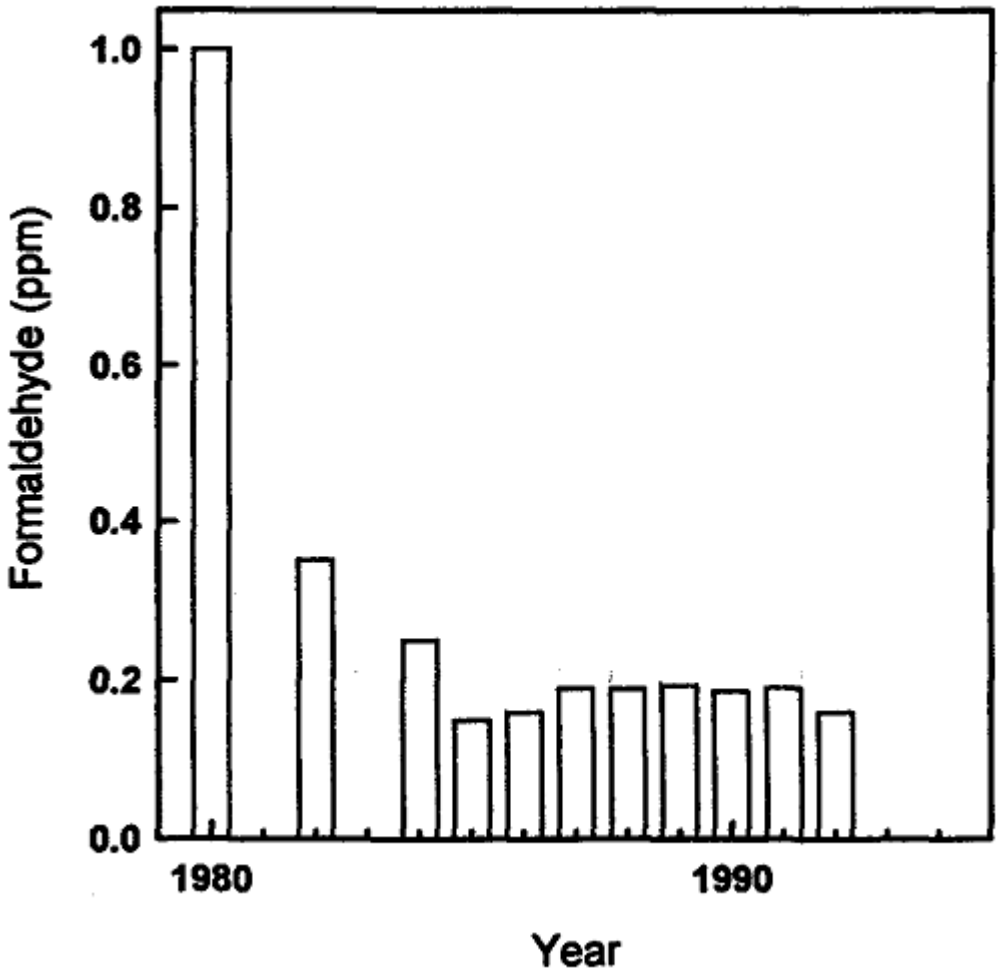

Figure 2.3.3.1-1: Average formaldehyde emission levels from particleboard manufactured in the year indicated. The levels were determined by the large chamber test method (National Particleboard Association & Conner, 1996).

In short, compulsory steps have to be taken to reduce the formaldehyde emission. One of the methods proposed by Myers, stated that reduction of formaldehyde to urea, F/U ratio seems promising (Myers, 1984). In his study, he found out that reduction of F/U ratio affected both the physical and mechanical properties of the wood composite board. With the credibility of these boards on the balance, the marketability of these products are also affected.

On top of that, a research done by Conner in 1996, he proposed several worthy methods to reduce formaldehyde emission. Besides reducing F/U ratio, he proposed for adding of formaldehyde-scavenging materials directly to urea formaldehyde adhesive resins, adding formaldehyde-scavenging material seperately to finished wood products, treating

wood panels with formaldehyde-scavenging by the application of coating or laminates, and utilization of a completely different adhesive resin system in production of wood composite (Conner, 1996). However, replacing urea formaldehyde could affect the quality of the wood product. For example, in a research, it was found thar replacing urea formaldehyde with amine adhesives affected its physical and mechanical properties (Boran, et al, 2011).However, replacing urea formaldehyde with acrylic resins showed better results in mechanical properties like lower water absorption, and lesser thickness swelling but did not effect its thermal insulation properties (Amazio, et al., 2011).

2.3.3 Test for formaldehyde emission

Risholm-Sundman, et al, studied upon the different tests carried out for formaldehyde emission in different countries. The study shown a significance importance being placed in order to compare products with formaldehyde emission classes like E1 in Europe and F*** and F**** in Japan (Risholm-Sundman, et al, 2007)

2.3.3.1 Standard test methods

There are five standard tests for formaldehyde emission determination. This determination is in accordance to reference methods stated in Europe and on Japan. Some of the methods characteristics are discussed by Yu and Crump in 1999 as shown in Figure 2.3.3.1-1 (Yu & Crump, 1999).

There are many differences between the European standard and the Japanese standards. The main reason why the results from each method differ is because of the testing conditions. The test conditions like temperature, relative humidity and air exchange rate varies (Que & Furuno, 2007). Besides that, type of resin, type of wood panels, thickness plays a role (Salem, Bohm, et al, 2011).

Another factor why the results differ is due to sample treatment (Risholm-Sundman, et al., 2007). Such examples are as follow:

- Edge and back sealed off, and
    - Some European flask method and Japanese desiccator method had its sample sealed at some placed to meet certain criteria.

- Conditioning prior to measurement.
    - Some samples are taken for results testing after probation period and some have to being conditioned to certain humidity level and temperature.

	Method	Test sample		Conditioning	Test conditions	
		Size loading factor	Edge sealing (m open edge m^{-2})	Temp/RH	Temp/RH	Air exchange/ hour
Europe	EN 717-1 0.225, 1 or $>12\,m^3$ chamber	$1\,m^2\,m^{-3}$	Partly ($1.5\,m\,m^{-2}$)	23 °C/45%[a]	23 °C/45%	1
	EN 717-2 gas analysis 41 chamber	0.4×0.05 m	Yes	Not stated	60 °C/⩽ 3%	15
	EN 717-3 500 mL flask	0.025×0.025 m, 20 g	No ($80\,m\,m^{-2}$)	Not stated	40 °C/˜100%	No
	EN 120 perforator	0.025×0.025 m, 110 g	No	Not stated	Toluene extraction at 110 °C	No
Japan	JIS A 1901 201 – $1\,m^3$ chamber	$2.2\,m^2\,m^{-3}$	Yes	28 °C/50%	28 °C/50%	0.5
	JIS A 1460 9–111 desiccator	$0.18\,m^2$	No ($27\,m\,m^{-2}$)	20 °C/65%	20 °C/0–80%[b]	No
	JAS 233 9–111 desiccator	$0.18\,m^2$	No ($27\,m\,m^{-2}$)	No[c]		No
Global	ISO/CD 12460 $1\,m^3$ chamber	$1\,m^2\,m^{-3}$	Partly ($1.5\,m\,m^{-2}$)	23 °C/50%[a]	23 °C/50%	1

[a]Conditioning in the chamber, the values reported are steady-state values.
[b]See Fig. 4.
[c]Stored at 20 °C for 1 day wrapped in plastic before testing.

Figure 2.3.3.1-1: Table of Comparison between standard methods for the determination of formaldehyde emission (Yu & Crump, 1999).

The five methods which are the standard method are as follow:

- Chamber methods,
- Gas analysis,
- Flask method,
- Perforator method, and
- Desiccator method.

2.3.3.1.1 Chamber method

In chamber method, the standard that guards its place is EN 717-1 and JIS A 1901. Under the European standard, the sample is placed in a chamber the size of 1 m^3 or 0.255 m^3 in volume. The temperature of the chamber is kept constant at 300.15 K and its relative humidity (RH) is at 45%. The air exchange rate is per an hour, 1 h^{-1} and loading factor is 1 m^2m^{-3}. The mechanism that follows is the formaldehyde released from the test samples mixes with the air in the chamber, and a specific volume of mixed air is drawn from the chamber twice a day. This formaldehyde is absorbed in impringer flask containing water and the concentration is determined photometrically (EN 717-1, European Standard, 2004).

In Japanese standards, a chamber of 20L is preferred. The loading factor is 2.2 m^2m^{-3} and the air exchange rate is 0.5 h^{-1}. The RH is at 50% with the temperature is at 28 ^oC. The results from this standard are measured as specific emission rate (EF) in µg $m^{-2}h^{-1}$. When the loading factor and air exchange rate is 1 in European chamber, the concentration result in mg m^{-3} is equal to EF results in mg $m^{-2}h^{-1}$ (same as Japanese standard).

2.3.3.1.2 Gas analysis

Gas analysis however is only specific to European standard, EN 717-2. In this method, determination of accelerated formaldehyde release from wood-panels is the focus. Similarly to the chamber method (EN 717-1), the sample is place in a controlled temperature, RH, airflow and pressure. Air is then drawn into a container and absorbed in water and immediately, the concentration of formaldehyde is determined photometrically (EN 717-1, 1994).

Usually, the temperature stated 60 ^oC and RH of $\leq$ 3% with air exchange rate of 15 h^{-1}.

2.3.3.1.3 Flask method

Likewise the gas analysis, flask method is also guided under European standards. Flask method, or in other terms, EN 717-3 have the same purpose as chamber method, to determine the formaldehyde emission from wood panel. However, the method carried out to execute this test is by placing a sample piece over water in an enclosed chamber or container for a period of time at constant pressure and temperature. After that period of time, the concentration of formaldehyde in water is determined photometrically. In

particular, the small piece of sample wood is placed in a large, air-tight container situated under immense temperature of 40 ^{o}C and high HR (EN 717-3, 1996).

2.3.3.1.4 Perforator method

EN 120 is the standard for perforator method. In this standard, the emission of formaldehyde in wood composite is determined using a perforator. First, the formaldehyde from the sample is extracted with boiling toluene and then transferred into water. The formaldehyde solution in the aqueous is determined photometrically and expressed in weight per 100g of dry board. The results are then correlated to standards due to its dependence to type of board as shown Figure 2.3.3.1-2. This method is still widely used but often questioned due to environment point of view (Risholm-Sundman, et al, 2007).

Formaldehyde emission measured according to different standard methods

Material		Thickness	Chamber	Gas analysis	Flask	Perforator	Chamber	Desiccator	
		(mm)	EN 717-1 ($mg\,m^{-3}$)	EN 717-2 ($mg\,m^{-2}\,h^{-1}$)	EN 717-3 ($mg\,kg^{-1}$)	EN 120 (mg per 100 g)	JIS A 1901 ($\mu g\,m^{-2}\,h^{-1}$)	JIS A 1460 ($mg\,l^{-1}$)	JAS 233 ($mg\,l^{-1}$)
Solid wood	Oak MC = 8%	20	0.005[a]	0.05[a]	0.06[a]	0.19[a]		<0.1 (0.00)[c]	<0.1 (0.03)[c]
	Pine MC = 8%	20	0.006[a]	0.3[b]	0.16[a]	0.23[a]		<0.1 (0.05)[c]	0.18
				0.09[a]					
Particle board	E0 MC = 6.8%	12	0.03	0.8	2	2–3		0.2	
	E1 MC = 6.0%	12	0.07	2	4	4.6		0.5	
Plywood	Interior MC = 8.6%	9.5	0.20	5.5	32				4.7
	Exterior MC = 6.2%	15	0.01	0.2	1.4				0.3
MDF	MC = 5.9%	12	0.10	4.4	3.5	7.5	74 (43 at 23 °C)	0.6	

[a]Value from Meyer and Boehme (1997).
[b]No conditioning.
[c]Analysed value, below the determination limit of 0.1 $mg\,l^{-1}$.

Figure 2.3.3.1-2: Formaldehyde emission measure according to different standard method to respect its type of board (EN 717-3, 1996 & Meyer & Boehme, 1997)